Mechanical Properties and PVC Creep

WBS 1.4.2

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Overview

- Motivation for creep study
- Creep and related terms
- Predictive methods
- Current results
- Literature references

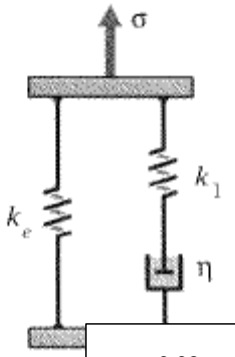
Creep modulus is THE driving mechanical property

- Typical structures (i.e. steel) are evaluated relative to yield stress, ultimate stress, and stiffness.
  - In typical PVC yield stress (>4000psi) and ultimate stress (>6000 psi) of PVC
- PVC is subject to creep
  - The rate of creep depends on the stress
- For this reason, the NOVA structure is designed to limit stresses below 700 psi in order to minimize the effects of long term creep
- The long term creep modulus is the driving design parameter

Estimating long term creep

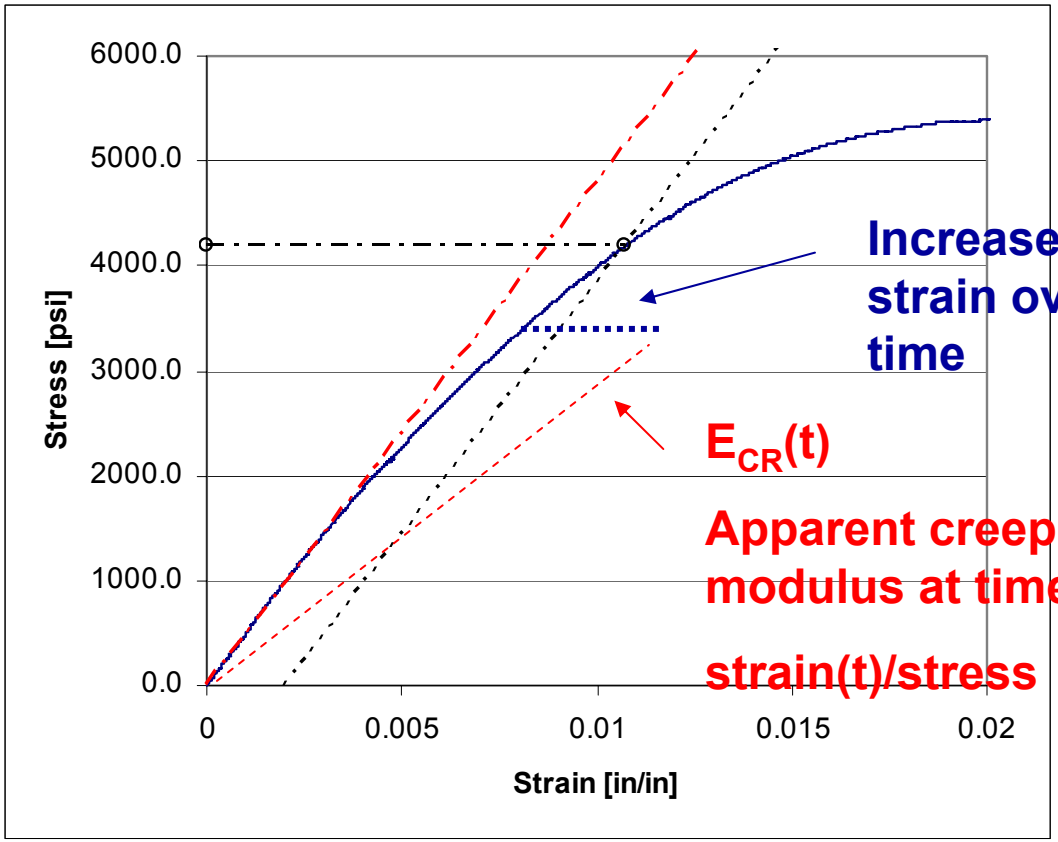
- Must understand creep of Nova PVC over the 20 year design lifetime
- We have determined a lower bound for the long term creep from:
  - Consultant prediction
  - Our own **accelerated** tests (at ANL and FNAL)
- We are verifying the estimates by:
  - Our own **long term** tests (at ANL and FNAL)
  - Literature references

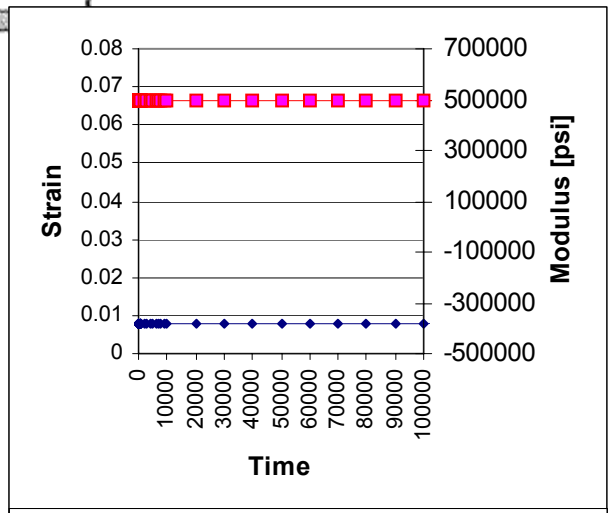
Review of Creep and Related Terms

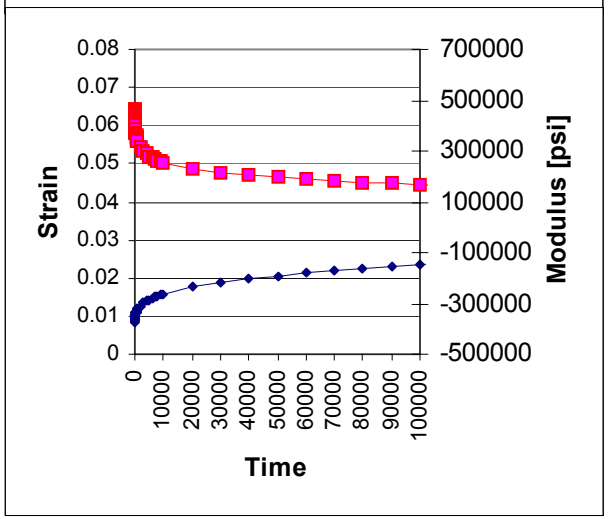


$$E_{cr}(t) = \frac{\sigma}{\varepsilon(t)}$$

- Elastic Modulus
- Strain versus time- Creep Modulus







Predicting long term creep from short term tests

- Viscoelastic mechanisms (i.e. creep) are temperature dependent - Increasing temperature accelerates the process
  - **Frequency-Time-Temperature-Superposition (FTTS)**
    - Compares phase response between applied stress and resulting strain)
  - **Time -Temperature Superposition (TTS)**
    - Tests performed at different temperatures
    - Results shifted along (log) time scale to create result as single temperature
- Long term creep tests
  - "Room temperature test"- 20 deg C
  - Extrapolation of existing data out one order of magnitude

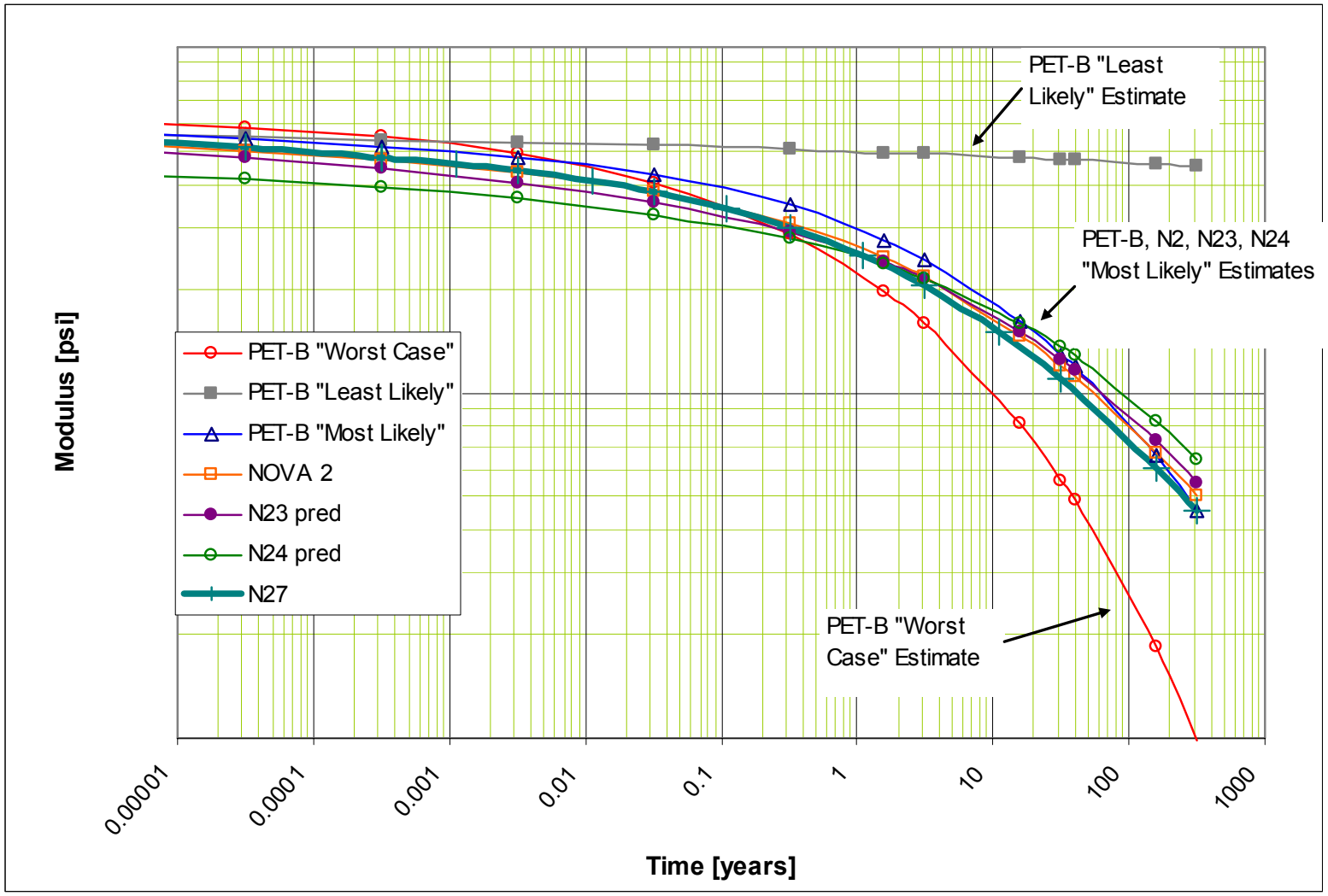
"It is recommended that at least two of these .. schemes be used..If two agree,..designer can be reasonably certain.."-ASM Engineered Materials Handbook (Eng. Plastics)

Current tests

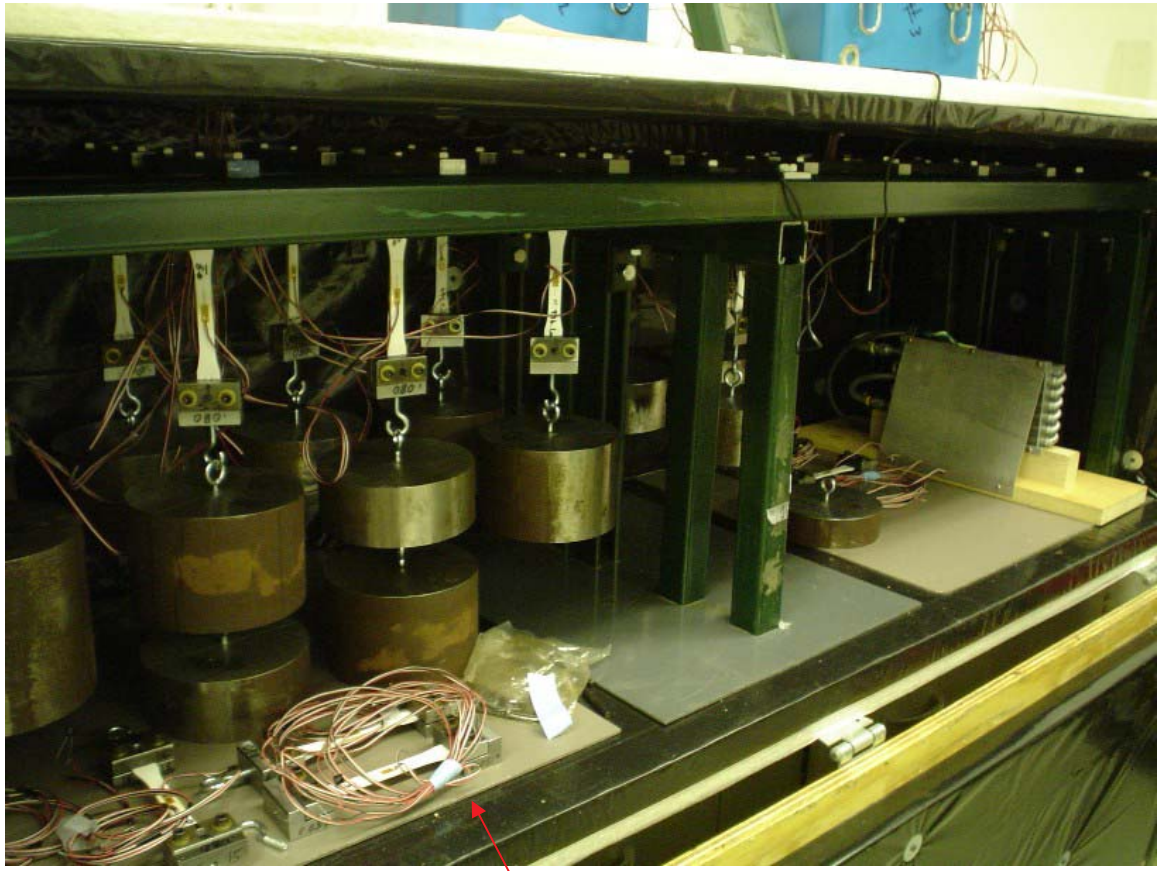
	Rutile			Anatase	
	PET-B	Nova 2	Nova 24	Nova 23	Nova 27
PVC	82%	77%	78%	75%	78%
Titanium Dioxide	15%			18%	15%
Lubricants/Stabilizers/ Processing aids	2.9%	4.2%	4.6%	4.5%	4.6%
Impact modifiers	0%	4%	3%	3%	

- Specialist hired to predict creep properties using (accelerated) FTTS method
  - PET-B prediction - Nova DocDB 667
  - NOVA 2 prediction - Nova DocDB 1042
  - NOVA 23,24 prediction - Nova DocDB 1326
  - NOVA 27 prediction – Nova DocDB 2113
- Long term “room temperature” (20 deg C)
- In-house accelerated Tensile Creep Tests (TTS)
  - Nova 2- Nova DocDB 1976
  - Nova 27- In progress

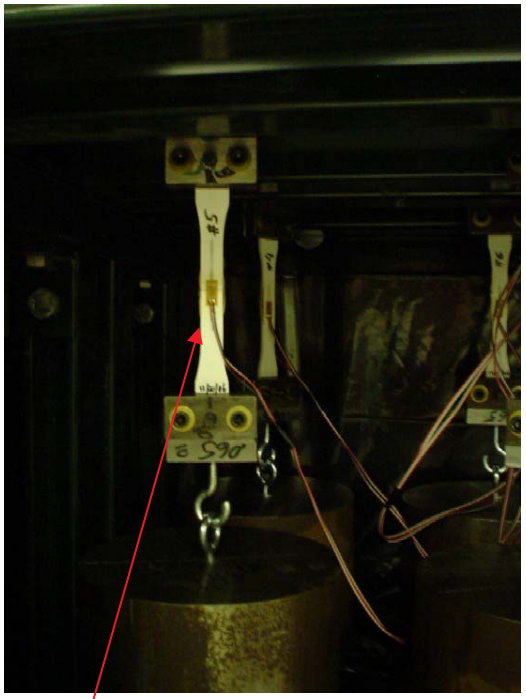
Comparison of predictions



Pictures of room temperature tests

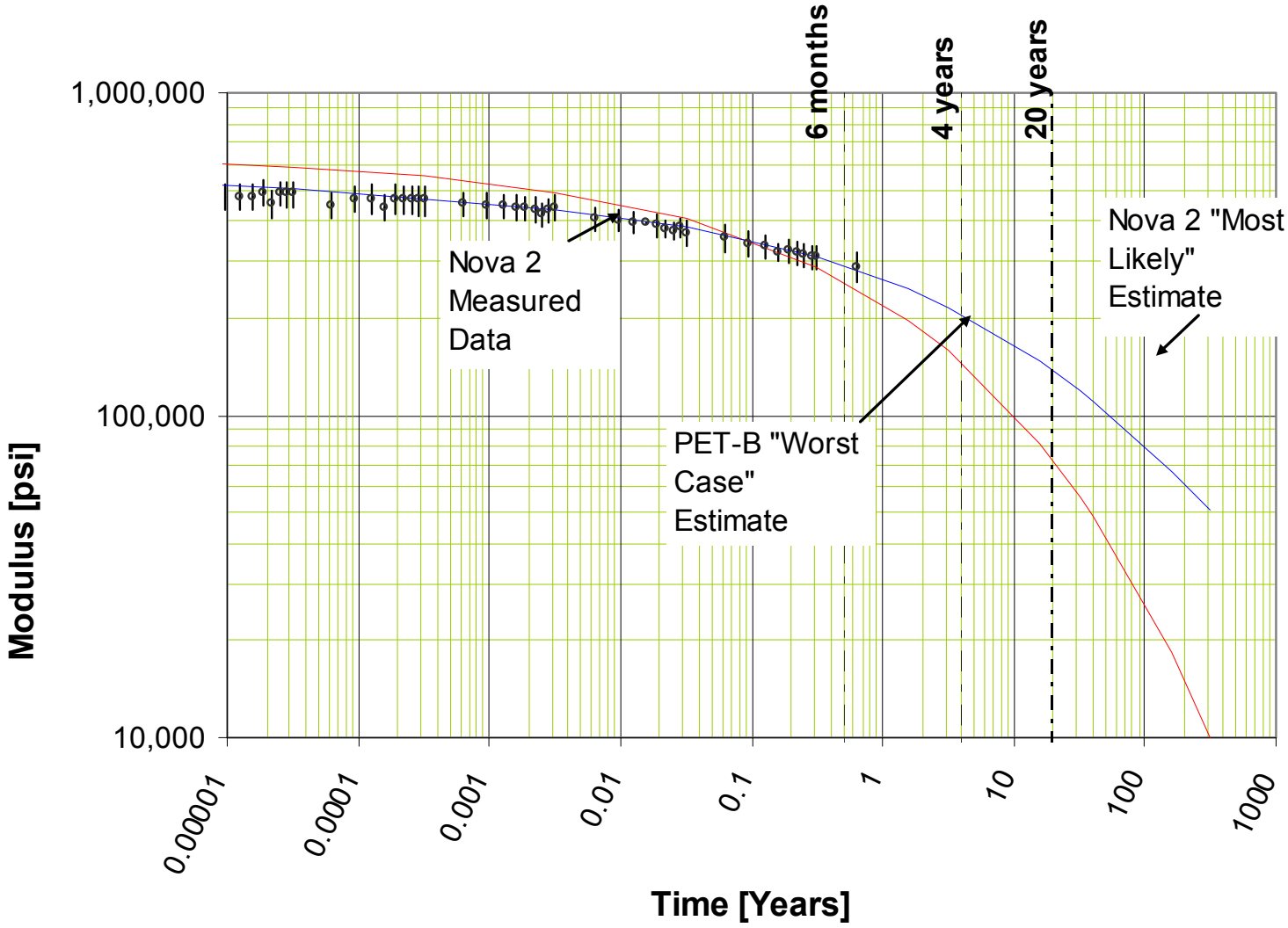


Note samples aging for future use

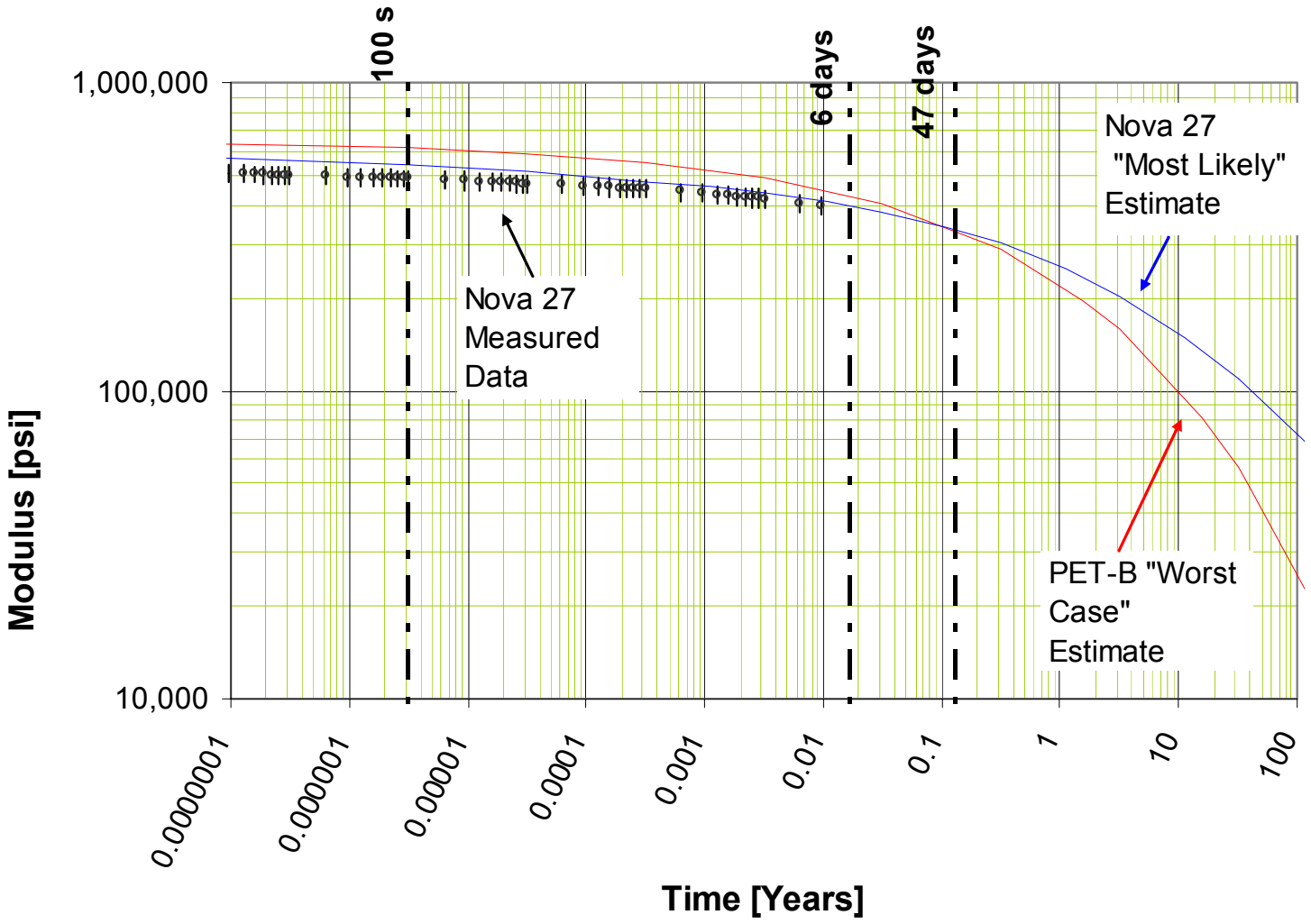


Strain gage

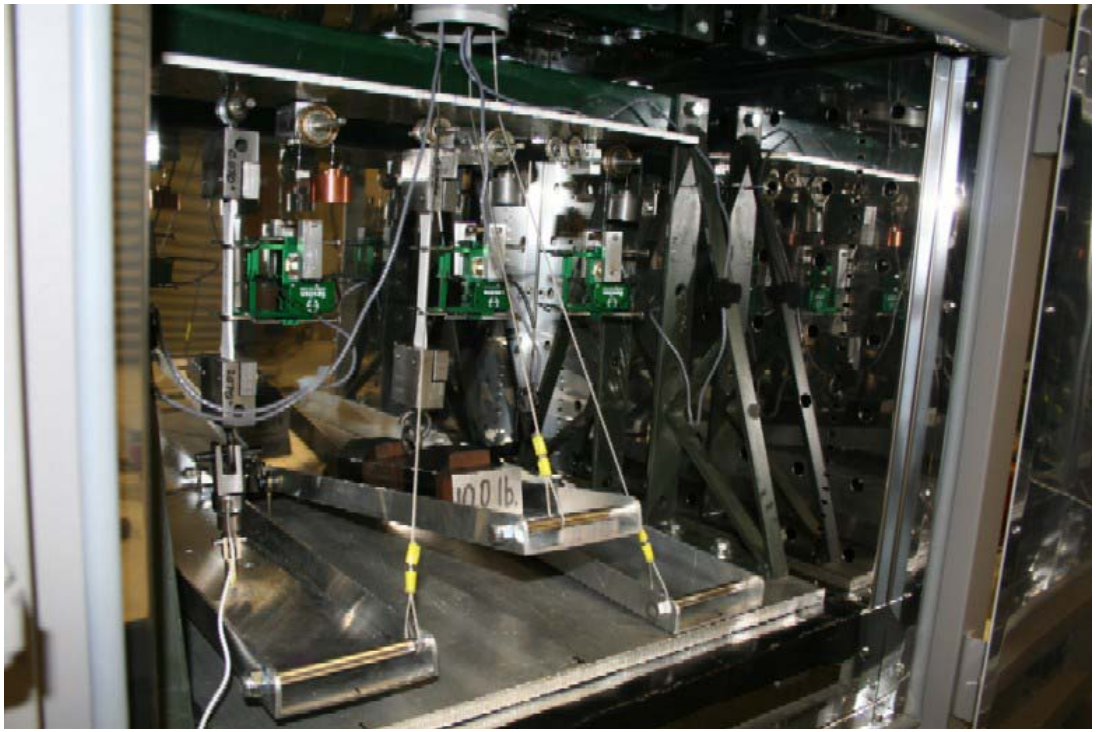
Nova 2(rutile) at 231 days compared to Predictions

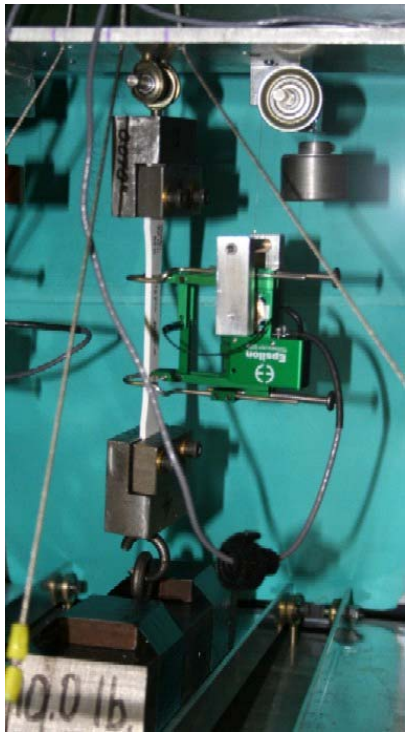


N27 (anatase) creep prediction

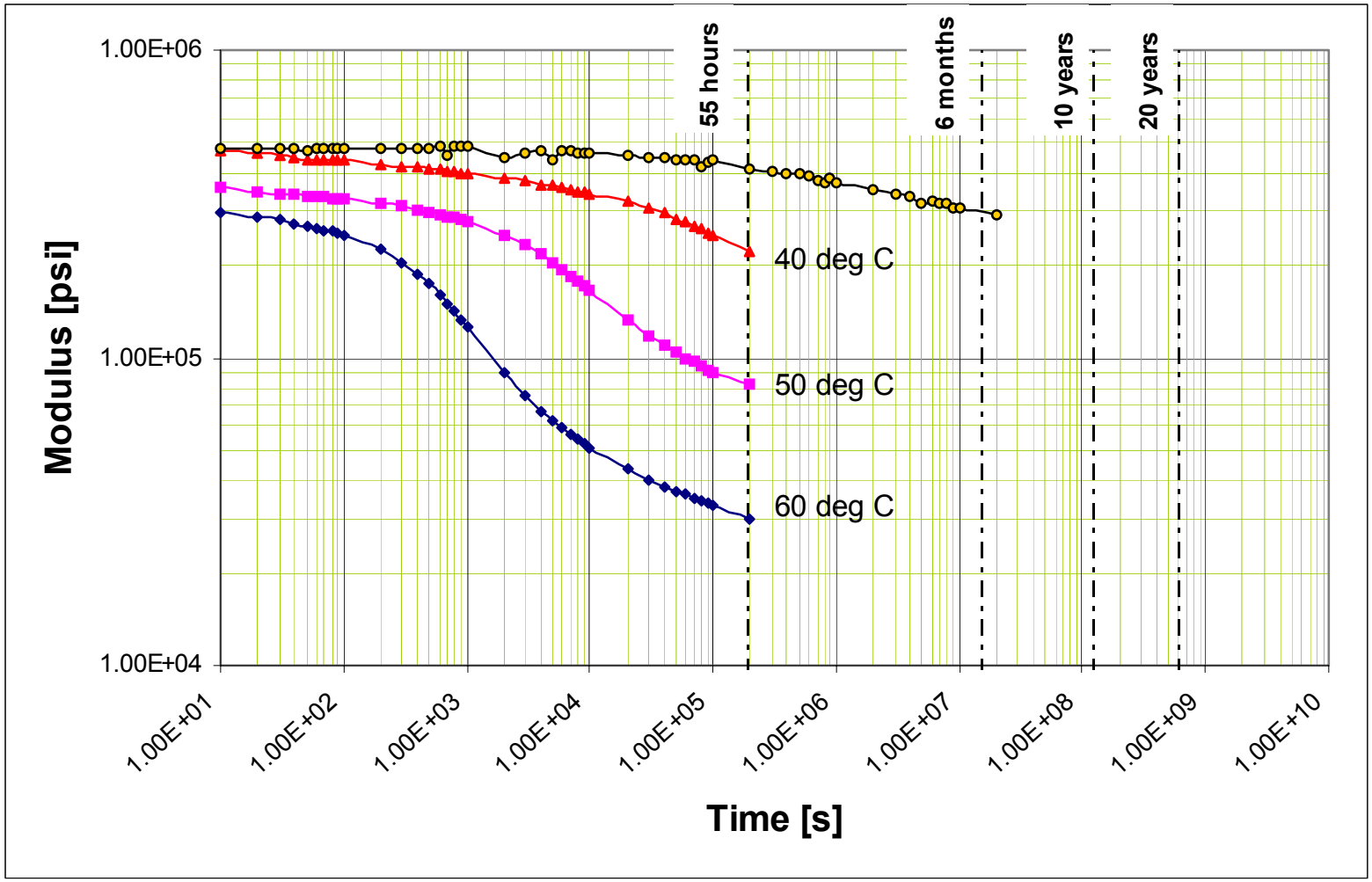


Elevated temperature Creep tests



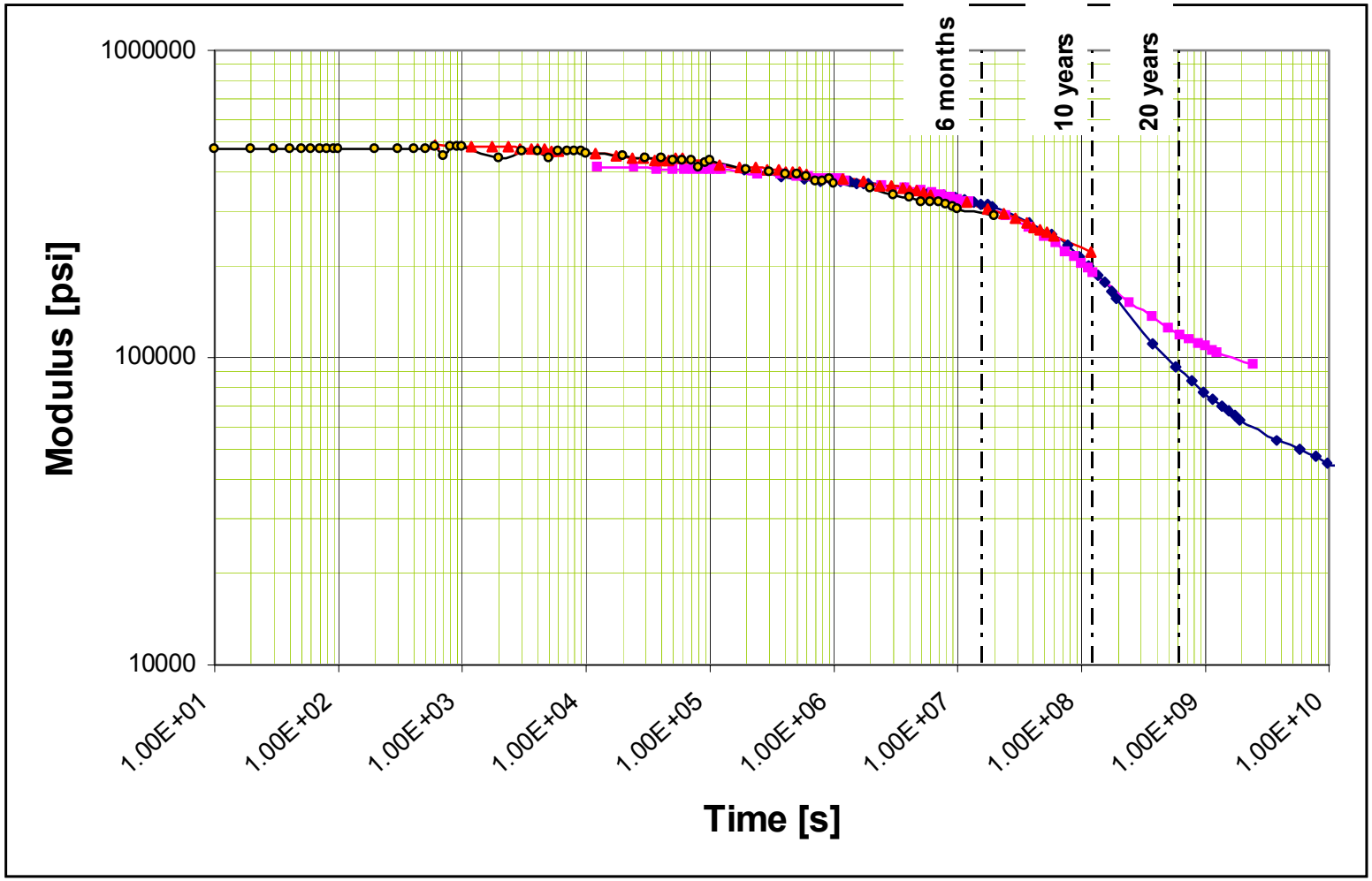


N2 Tensile Creep Modulus at various temperatures (real time data)

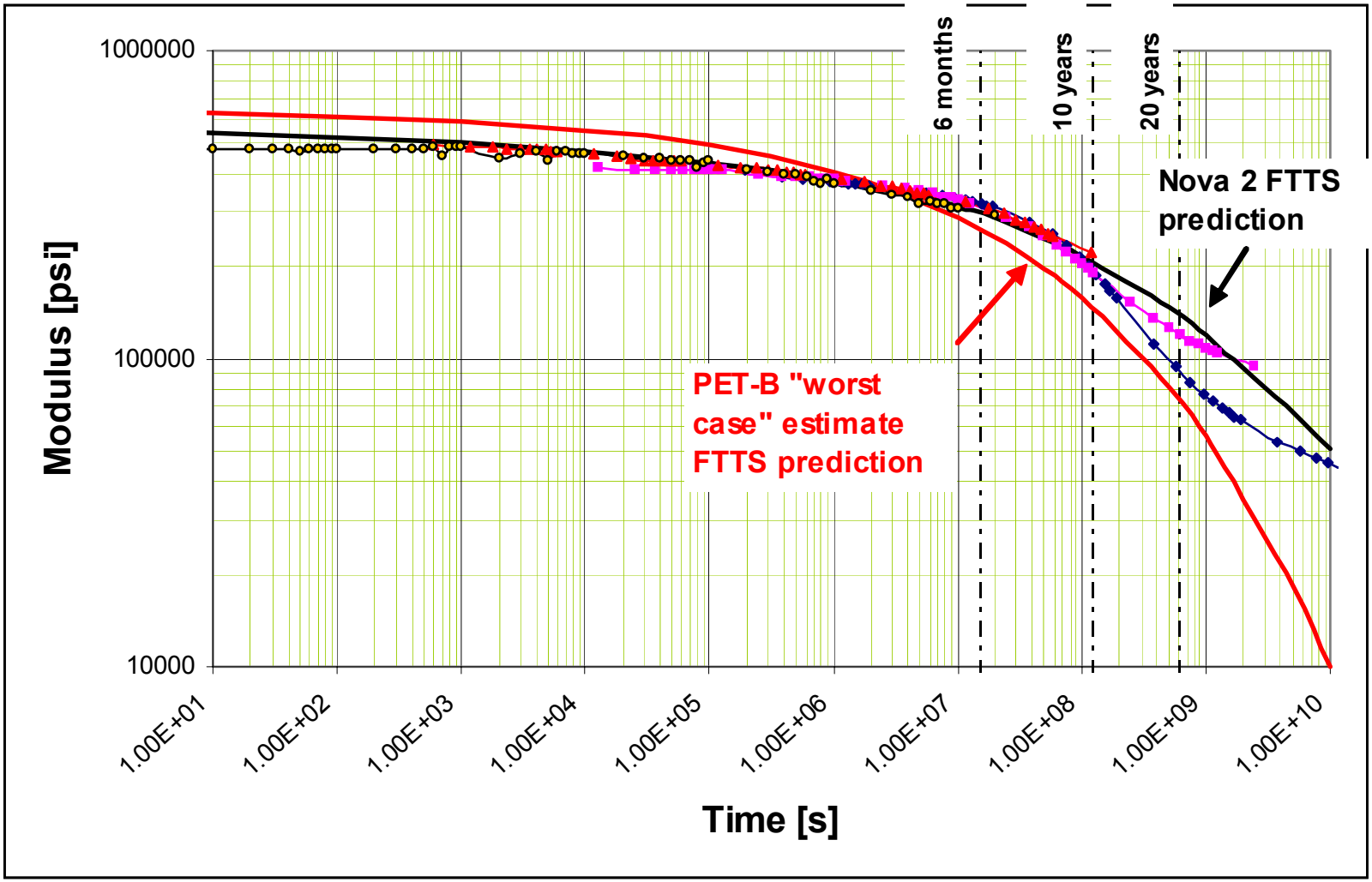


N2 Creep Master Curve at 20ºC from TTS

(from horizontally and vertically shifted higher temperature curves)



Comparison of FTTS, TTS and long term room temperature data



Conclusion

- FTTS Predictions of different PVC formulations are consistent with each other
  - This is expected as base PVC is identical, formulations are similar
  - No difference between anatase or rutile TiO_2
- TTS prediction consistent with FTTS to 4 years
- Long term (room temperature) data of N2 creep validates predictions
  - N2 creep data is consistent with predictions (at 231 days)
- N27 prediction of creep modulus exceeds the conservative (PET-B “worst case”) value used in analysis